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A Method of Comparing 3-D Image Consistency and Quality Between Commercially Available 3-D Scanners

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ABSTRACT

With a number of 3-D scanners now available commercially, little work has been done to directly compare their capabilities. This study was designed to characterize differences between the Vitronic Vitus Pro scanner owned by TNO in the Netherlands and the Cyberware WB4 scanner owned by AFRL/HECP at Wright-Patterson Air Force Base. For the purpose of the study, the Cyberware scanner was transported to the TNO facility in the Netherlands. Ten male and ten female subjects were scanned three times in each of three poses in both scanners. All scans for a subject were taken in one session. 3-D image data were segmented, aligned and compared using a difference mapping algorithm. The Cyberware scanner yielded useable data for all twenty subjects; however, the scans from the Vitronics scanner were of higher resolution. This method can be used to compare scanners or poses.

INTRODUCTION

The Civilian American and European Surface Anthropometry Resource (CAESAR) project was a 3-D anthropometric survey of the civilian populations of three countries: the United States of America (USA), The Netherlands, and Italy[1,2]. It was carried out by the U.S. Air Force, with the help of 1) the contractor, Sytronics Inc., 2) The Netherlands Organization for Applied Scientific Research (TNO) and 3) a consortium of companies under the umbrella of the Society of Automotive Engineers (SAE). The CAESAR project data collection protocols were deliberately designed to be independent of the particular 3-D whole-body scanner used to collect data. Data were collected in North America and Italy using a Cyberware WB4 scanner owned by AFRL/HECP at Wright-Patterson Air Force Base, and in the Netherlands using a Vitronic Vitus Pro scanner owned by TNO.

During the course of the survey we noted some differences in the scans produced by these two scanners. In order to determine if the particular scanner used might introduce bias into the data, we conducted a side-by-side systematic comparison study of these two scanners. The techniques developed for this comparison study can be used as a model for evaluating and comparing the images produced by different scanners in the future.

METHOD

In order to compare scan results for the two scanners, the Cyberware WB4 scanner was transported to the TNO facility in Soesterberg, The Netherlands, and set up in close proximity to the Vitronic Vitus Pro scanner there. The general procedure was to scan twenty subjects in each scanner using identical protocols. All data collection for a particular subject was carried out in a single session, to ensure the subject's size and shape remained constant. Three scans of each subject were made in each of three poses in each scanner. These scans were later processed and aligned, and a radial difference mapping technique used to derive data on the similarity of repeated scans of the same subjects in each scanner.

SUBJECTS

The subjects were ten healthy male and ten healthy female subjects recruited locally to TNO. Table 1 presents selected statistics of this group.

Table 1: Selected statistics of study subjects.

Subject	Gender	Age	Weight, kg	Stature, cm
1	M	25	58	170
2	F	18	64	165
3	M	21	70	186
4	F	27	85	178
5	M	23	61	179
6	M	19	111	192
7	M	21	80	183

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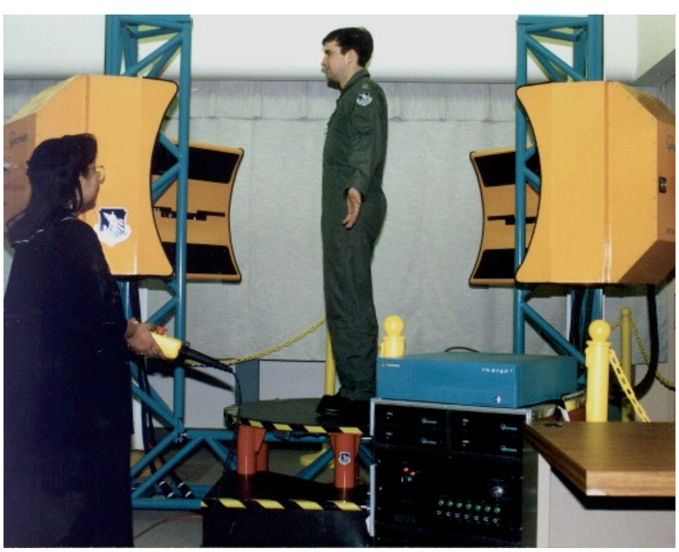
12	F	21	51	167
13	F	18	76	177
14	F	26	72	181
15	M	26	64	175
16	F	21	61	169
17	F	20	66	168
18	M	19	80	168
19	M	23	107	199
20	F	18	85	168

THE CYBERWARE WB4 SCANNER

The Cyberware WB4 scanner consists of four scan heads, each of which has two (2) lasers, a range camera and a color camera. The scan heads are attached in pairs andmove from the top of the scanner to the bottom, collecting data as they move. All of the lasers on each pair of scan heads are aligned to produce a single plane of light as the scan heads move, and the range and color cameras collect a row of data for every two (2) millimeters (mm) of travel. After the scan process is complete, color data is matched to range data by a mathematical model that assigns a color pixel to each point on the range data. During assembly and setup of the scanner, the color-range mapping parameters are calibrated and checked to minimize the possible error introduced by the color mapping process. Similarly, the range data from each head is calibrated to minimize errors among the scan heads. When this process is complete, the WB4 scanner is accurate within one (1) mm at all points within the scan field.

Figure 1. The Cyberware WB4 3-D laser scanner.



The data from the four (4) scan heads is merged into a single dataset by a Cyberware-supplied program called CyPie, after which the data is in a form and format that can be used to visualize, analyze, and manipulate the data to extract information from the dataset as needed using a CARD-Lab-developed program called INTEGRATE[3].

THE VITRONIC VITUS PRO SCANNER

The Vitronic Vitus Pro scanner consists of four scan heads, each of which has one (1) laser, four (4) range cameras and a color camera. The scan heads are attached in pairs to a pair of transport mechanisms that move from the top of the scanner to the bottom, collecting data as they move. All of the lasers on each pair of scan heads are aligned to produce a single plane of light as the scan heads move, and the range and color cameras collect a row of data for every one (1) to two (2) millimeters (mm) of travel. After the scan process is complete, color data is matched to range data by a mathematical model that assigns a color pixel to each point on the range data. During assembly and setup of the scanner, the color-range mapping parameters are calibrated and checked to minimize the possible error introduced by the color mapping process.

Figure 2. The Vitronic Vitus Pro 3-D laser scanner.

Both the WB4 and the Vitus Pro are factory-calibrated, but the process for fine alignment of the Vitus Pro range data is significantly different from the process used for the WB4. The fine alignment process for the WB4 determines correction factors that are then applied to all subsequent scans until another alignment check is performed. This alignment correction process is a function of the CyPie software. The fine alignment

process for the Vitus Pro is done for each scan, using the IMAlign module from an Innovmetric software package called Polyworks[4].

DATA COLLECTION

When the final alignments and merges are complete, the WB4 datasets and the Vitus Pro datasets are oriented differently, making direct comparison between the datasets more complicated. In order to use the same scripts and processes on both types of data for this study, the Vitus Pro datasets were mathematically transformed to a position and orientation very similar to the default position and orientation of the WB4 datasets before any analysis was attempted. This transformation process consisted of loading a dataset of each type in similar poses into INTEGRATE, rotating and translating the Vitus Pro dataset to closely match the WB4 dataset, then saving the resulting displacement matrix for application to all future Vitus Pro datasets before analysis.

Figure 3. 3-D scan showing surface color information; landmark markers are visible in this view.

Landmarks were captured by placing markers at the time of scanning on each subject at pre-determined positions representing an important point for either measurement or segmentation. These landmarks are visible in the scan data, and are usually positioned over bony points that are not otherwise directly visible on the scan and must be placed by palpation of the area to determine the exact bone position. Landmark coordinates are extracted from the scan by using either a semi-automated procedure for large volumes of data (e.g. CAESAR) or by an entirely manual process using INTEGRATE for smaller volumes of data such as this comparison study. A quality-control check at the end of landmark extraction ensures that either process produces accurate landmark coordinates.

Datasets were segmented according to McConville et al, 1980[5], using the scan coordinates of landmarks placed on each subject and extracted from the scans as noted above. In this study, only the thorax segment was of interest, and only the standing poses were used. Segmenting the thorax required cuts at the neck to remove the head and neck, a cut at the bottom of the rib cage to remove the lower torso and legs, and a cut at each shoulder to remove the arms. Segments were aligned by using a least-squares fit between the thoracic landmarks on different scans.

Figure 4. Segmentation according to McConville et al, with the thorax highlighted.

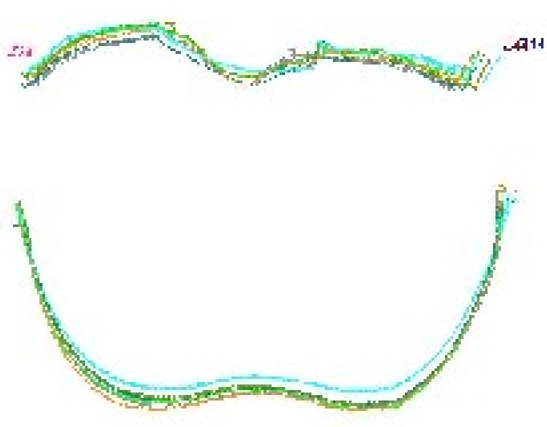
DATA ANALYSIS

Data were tabulated in cylindrical coordinates corresponding to a cylinder about each subject's vertical axis. For each subject, all Cyberware WB4 standing thorax scans were aligned, using the first scan as

reference. The first Vitronic Vitus Pro standing thorax scan for that subject was then aligned to the first WB4 scan, and then the other two Vitus Pro scans aligned to the first Vitus Pro scan. The purpose of this alignment is to ensure that all of the scans share the same vertical axis. Using the vertical axis as a reference, we could define a cylindrical coordinate system. In this system Y represents the elevation from the bottom of the scan; each elevation Y defines a horizontal plane at that elevation. Theta represents the angular direction of a line drawn from the vertical axis to any point on the surface (imagine a compass needle pointing from the central axis); this angle was defined with respect to an arbitrarily chosen reference direction. Radius, R, represents the horizontal distance from the vertical axis to the scan surface.

A data file was created containing the orientation angle theta, the elevation Y, and the three radii (R1, R2, and R3) corresponding to the three scans of that subject in that scanner for that theta and Y. Theta was stepped in increments of .01 radians (this produced 628 points around the circumference) to give a horizontal resolution around 1.3 mm (depending on exact radius). Elevation Y was incremented by 2 mm, so point (1,1) is .01 radians clockwise (looking from top) and 2 mm above point (0,0). A void data point was flagged as 9999.9. Then in order to facilitate processing, only every third line of data was retained. Lines of data were also discarded if any of the three radii at that theta and Y had missing data. For each subject in each scanner, the resulting data files contained on the order of 20,000 lines of data.

Figure 5. Scan data from one subject: a cross section through one elevation at the bust showing the six scans (three per scanner) after alignment.



Next, radial differences were calculated as follows: R1-R2, R1-R3, and R2-R3. For each of these differences in each subject/scanner, then, the following four parameters were calculated using Statistica[6]: Lines (number of lines of data), raddiff (the mean R1-R2 difference for that subject/scanner, the mean R1-R3 difference, etc.), vardiff (variance of the differences), and absraddiff (mean of the absolute values of the R1-R2, R2-R3, etc. differences). These parameters were compiled into a data file of 120 lines (i.e. twenty subjects by two scanners by three scans each), containing the following data: subject number, scanner, difference number (R1-R2 = 1, R1-R3 = 2, and R2-R3 = 3), and the parameters: lines, raddiff, vardiff, and absraddiff.

SAS[7] was used to perform ANOVAs for the four parameters by scanner and by subject. It was anticipated that the image consistency differences due to the scanners themselves would be less than the differences due to individual subjects; for this reason, analyses were performed by subject as well as by scanner.

Figure 6 shows a radial difference map comparing the two scans. The color key is provided in Table 2. The radial difference map allows us to visualize the areas in which the two scan tended to differ, and to visually determine if systematic differences might exist.

Figure 6. Radial difference map comparing the radii of two scans at each elevation, for one subject.

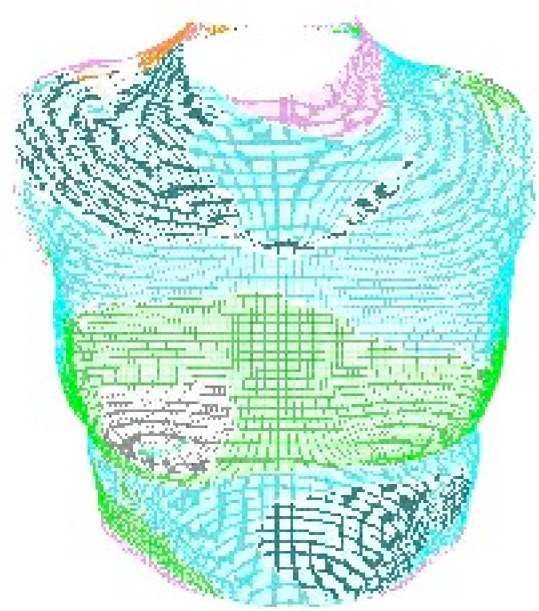


Table 2: Color key to the radial difference map, Figure 6.

Radial Difference Map Color Codes	Minimum	Maximum
Light Cyan	0	+5
Dark Blue-Gray	+5	+10
Orange	+10	+15
Light Red	+15	+20
Magenta	+20	above
Green	0	-5
Gray	-5	-10
Light Green	-10	below

RESULTS

The Vitronic Vitus Pro scans of two of the subjects, subjects 2 and 16, were unusable due to poor quality. As a result, there were 18 subjects' data for the Vitronic Vitus Pro and 20 subjects' data for the Cyberware WB4.

NUMBER OF DATA LINES

There was a significant effect of scanner type on n lines of data in each subject/scanner data file, as well as a significant effect of subject. The mean number of lines of data per subject/scanner file was greater for the Vitronic than for the Cyberware scanner. This means the Vitronic scans had higher resolution than the Cyberware scans, an effect that Table 4 shows to be significant.

Table 3: Means by scanner of the lines in the scanner/subject data file.

Scanner	Number of subjects	Lines	Standard Deviation
Vitronic	54	13125.5	1778.231
Cyberware	60	12757.2	1833.621

Table 4: ANOVA results for the number of lines in the scanner/subject data file, showing a significant effect of scanner, as well as a significant effect of subject (DF is Degrees of Freedom).

Source	DF	Type I Sum of Squares	Mean Square	F	p
SCANNER	1	3855171	3855171	>99k	0.0001
SUBJECT	19	3.03E+8	15933143	>99k	0.0001

Table 4 shows a significant effect of subject, which was expected. Larger subjects have more data because they physically occupy more of the scan space.

RADIAL DIFFERENCES

There was no effect of scanner in the radddiff parameter; however, there was a marginal effect by subject.

Table 5: Means by scanner of raddiff.

Scanner	Number of subjects	Raddiff	Standard Deviation
Vitronic	54	-0.17264	0.878643
Cyberware	60	-0.14382	0.826492

Table 6: ANOVA results for raddiff, showing no effect of scanner upon mean radial difference, but a marginal effect of subject.

Source	DF	Type I Sum of Squares	Mean Square	F	p
SCANNER	1	0.02361	0.02361	0.04	0.8459
SUBJECT	19	18.04342	0.949654	1.53	0.0991

VARDIFF

There was no effect of scanner on the variances associated with the radial differences. There was, however, a highly significant effect of subject. This result may have to do with such variables as the relative ability of a particular subject to obey the experimenter's instructions to repeat the poses exactly, or the amount of soft tissue. Differences due to breathing could also show up here.

Table 7: Means by scanner of the variances of the mean radial differences.

Scanner	Number of subjects	Vardiff	Standard Deviation
Vitronic	54	21.77078	21.84079
Cyberware	60	26.18844	22.73621

Table 8: ANOVA results for vardiff in the scanner/subject data files.

Source	DF	Type I Sum of Squares	Mean Square	F	p
SCANNER	1	554.6571	554.6571	2.37	0.1282
SUBJECT	19	23140.54	1217.923	5.19	0.0001

ABSOLUTE VALUES OF RADIAL DIFFERENCES

When absraddiff were examined, instead of the signed differences (raddiff), the result was the same: an effect of subject was revealed, but not of scanner.

Table 9: Means by scanner of absraddiff.

Scanner	Number of subjects	Absraddiff	Standard Deviation
Vitronic	54	0.75524	0.470352
Cyberware	60	0.664379	0.505217

Table 10: ANOVA results for the means of the absolute value of mean radial differences in the scanner/subject data files.

Source	DF	Type I Sum of Squares	Mean Square	F	p
SCANNER	1	0.234641	0.234641	1.27	0.2626
SUBJECT	19	7.040888	0.370573	2.01	0.0172

CONCLUSION

No significant effects of scanner were revealed in any parameter except for the number of lines of data per subject/scanner data file. This means they are equally consistent in their measurement of a subject. The Vitronic scanner yielded data files with a larger number of data lines, corresponding to fewer bad data lines having been culled and higher resolution. The Cyberware scanner produced valid image files for all twenty subjects, whereas two subjects had to be dropped from the Vitronic analysis because of severe image quality problems. The results demonstrate that this method is effective for measuring resolution and consistency differences in scanners, as well as the consistency of subject pose effects; therefore, it can be used to evaluate both scanners and poses for experimental design planning.

Despite having segmented the scans and aligned them, we had anticipated that three consecutive scans of the same subject would not be identical. It is difficult for a person to pose identically, particularly in the spine and shoulders. Our data bear out the notion that within-subject variability in a scanner would be greater than scanner-related effects.

For evaluating scanners, it would also be desirable to eliminate the variability due to a subject's posture by performing this study using a rigid calibration object, such as was used previously to examine the accuracy of the Cyberware WB4 scanner[8]. The calibration object could be scanned three times in each scanner, and because the object's dimensions are not subject to change with time as human subjects are, the object could be shipped from the location of one scanner to the location of the other, eliminating the need to ship one of the scanners.

There are a number of valuable uses still untapped for the data from this comparison study. Most interesting is the ability to study systematic data bias in one scanner versus the other. This would be accomplished using the same method by comparing the location of the surface of scans from one scanner versus the other when the scans are registered to the same axis. In other words, the registration and comparison of interest would be between scanner instead of within scanner. In addition, these data offer the ability to study soft tissue deformation as a function of pose. We can segment and align subject scans from different poses. The differences we find, within a scanner for the same subject, will be due to the deformation of tissue about the fixed landmarks that is not removed through alignment. Analysis of these data to shed light on the soft tissue deformation issue is underway.

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REFERENCES

1. Robinette, K.; Daanen, H.; Paquet, E. (1999). The CAESAR Project: A 3-D Surface Anthropometry Survey, in *Second International Conference on 3-D Digital Imaging and Modeling, 1999. Proceedings.* pp. 380-386. IEEE Catalog Number: PR00062. IEEE: New Brunswick, N.J.
2. Robinette, K. (2000). CAESAR Measures Up, in *Ergonomics in Design*, Vol. 8, No. 3, pp 17-23. Human Factors and Ergonomics Society : Santa Monica, CA.
3. Burnsides, D; Files, P.; and Whitestone, J. (1996). *Integrate: A prototype for evaluating three-dimensional visualization, analysis, and manipulation functionality* (AL/CF-TR-1996-0095). CARD Laboratory, Crew Systems Directorate, Human Engineering Division, Wright-Patterson Air Force Base, OH.
4. InnovMetric Software Inc. *Polyworks.* InnovMetric: Sainte-Foy, Canada.
5. McConville, J.; Clauser, C.; Churchill, T.; Cuzzi, J.; and Kaleps, I. (1980). Anthropometric Relationships of Body and Body Segment Moments of Inertia (AFAMRL-TR-80-119). Air Force Aerospace Medical Research Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, OH.
6. Statsoft, Inc (2000). STATISTICA for Windows (Computer program manual). StatSoft, Inc.: Tulsa, OK.
7. SAS Institute Inc. (1996). *SAS Proprietary Software Release 6.11.* Cary, NC: SAS Institute Inc.
8. Daanen, H.; Brunsman, M.; and Taylor, S. (1997). Absolute Accuracy of the Cyberware WB4 Whole Body Scanner (AL/CF-TR-1997-0046). Crew Systems Directorate, Human Engineering Division, Wright-Patterson Air Force Base, OH.

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